Soil Temperature Fluctuations in the Kikuyu Grasslands of Hawaii

H.R. Mount[1], R.T. Gavenda[2], S. Nakamura[3], and C. Smith[3]
United States Department of Agriculture – Natural Resources Conservation Service,
[1]Lincoln, Nebraska; [2]Kealakekua, Hawaii; and [3]Honolulu, Hawaii.

BACKGROUND & PURPOSE

The island of Hawaii, with a surface area of only 10,455 km², exhibits a wide range of climatic diversity with that found on larger continents. The soil temperature at 10-cm near the summit of Mauna Kea at 4,205 meters approaches 0ºC during the winter months while they are 25ºC warmer in the coastal areas less than 42 km away. It is well know that the soil temperature responds differently beneath different kinds of vegetation (Smith et al., 1964). The primary purpose of this study in Hawaii was to measure and analyze soil temperature at ten sites during 1998 and 1999 reflecting the dominant climatic areas of the Island. Four of these sites located beneath a thick carpet of Kikuyu grass (Pennisetum clandestinum) are summarized in this report **(Figure 1)**. Another purpose was to verify the measured data with the hypothesized soil temperature regime.

STUDY AREA

The Big Island of Hawaii is located in the tropics; that zone between the Tropic of Cancer and the Tropic of Capricorn. Hawaii is between 18° 56' and 21°16' north of the equator and is between 154°48' and 156°2' west of the Prime Meridian. The study consists of four sites in kikuyu grass. NRCS soil scientists in Hawaii selected these sites to best answer questions about the daily, monthly, seasonal, and annual soil temperatures for this study. The mean annual precipitation at these sites varies from 600 mm at the Parker HQ site near the town of Waimea to over 1500 mm at the Kona 1 and Kona 2 sites located southeast of the town of Captain Cook (Juki et al., 1992). The soils and landscapes at each site are formed by volcanic activity. The soil at Kona site 1 is shallow to pahoihoi, a smooth volcanic bedrock material that is 1500 to 2000 years old. This soil classifies as an isothermic Lithic Udifolist. The soil at Kona site 2 is moderately deep to a'a, a coarse volcanic bedrock material. Here the soil classifies as a medial-skeletal, isothermic Typic Hydrudand. At the Parker HQ site, the soil classifies as a medial, amorphic, isothermic Pachic Haplustand. The soil at the Hanaipoe site classifies as a medial, amorphic, isomesic Pachic Haplustand and is deep to hard bedrock (Soil Survey Staff, 1998), **(Figure 2)**. Additional site characteristics are presented in **Table 1**.

Kikuyu grass (Pennisetum clandestinum) and other tropical grasses occupy over 412,000 ha in the State of Hawaii and over 200,000 ha in the Big Island of Hawaii [NRCS NRI Data. 1994. 1992 National Resources Inventory. http://www.nhq.nrcs.usda.gov/NRI/tables]. Kikuyu grass is the preferred species for the ranch mangers on Big Island. Prior to this study, the daily, seasonal, and annual responses of soil temperature beneath these grasslands were not known. Kikuyu grass is a warm season, mid-green, coarsely textured grass imported from Australia **(Figure 3)**. Being hardy and easily controlled by withholding water and fertilizer, it performs well in Hawaii.

MATERIALS & METHODS

StowAway® temperature loggers store a maximum of 1,800 data points during periods ranging from 15 minutes to 360 days. Prior to installation at most of the sites in RSTN, StowAway® temperature loggers were programmed to collect data every 4 hours and 48 minutes for 360 days. Site installation was initiated by digging a hole with a sharpshooter to a depth of 50-cm (20 in). Site data were collected and the soils briefly examined to gather a taxonomic classification. One temperature sensor lead was tied to a bush or sapling at five sites to capture air and generally placed from 0.9 to 1.2 m (3 to 4 ft) above the soil surface. Two soil temperature sensor leads were installed at each site - one at the 10-cm (4-in) soil depth and one at the 50-cm soil depth. Due to a lack of suitable vegetation, a third soil sensor was added at 20-cm for sites 3 and 10. All of the sites were installed during early February 1998. After retrieval of the temperature loggers, over 21,000 discrete temperature values were used for this study. Temperature data were averaged by month and an annual average was then determined. In addition to Mean Annual Air Temperature (MAAT) and Mean Annual Soil Temperature (MAST), a Mean Summer Temperature (MST) and a Mean Winter Temperature (MWT) were calculated. The MST is the average for all the readings during June, July, and August while the MWT is the average for all the readings during December, January, and February. An isotivity value, or the difference between MST and MWT, was determined at each of the sites to access the extreme seasonal variation.

RESULTS

Mean Annual Air Temperature (MAAT)

At 17.7ºC, the MAAT for the Parker HQ site in Waimea is similar to long-term data indicating an average of 18.2ºC (Meteorological Staff, 1983). When using the daily low and daily high values collected during the period of record of this study to calculate the average at Waimea, it is 18.8ºC. Both methods used to determine a MAAT at the Parker HQ site in Waimea resulted in averages that approximate the long-term average.

Mean Annual Soil Temperature (MAST)

Table 3 shows the averages for MAST at 10 cm. All differ by than less than 5ºC between MST and MWT. These data infer that the soils beneath the kikuyu grasslands in Hawaii would classify as 'iso' even if bedrock terminated the soils at 10 cm. The three Isomesic sites have a MAST within 0.5ºC though they differ considerably in elevation and mean precipitation. The Kona sites are 0.8 km apart with similar soil and site conditions yet differ by this same amount. Monthly temperature averages and annual summaries for the 38- and 50-cm soil depths are shown in **Table 2**. These data show that all sites are Isothermic except for the Hanaipoe site, which is Isomesic. The annual averages for the Kona sites and the site at Parker HQ are similar. The higher altitude site at Hanaipoe averages more than 4ºC colder.

Data for monthly soil temperature averages are shown in **Table 2**.

Upon examining the soils beneath kikuyu grass, a pattern emerges. The 10-cm soil depth is consistently colder for all month than the 50-cm depth at all sites. The monthly soil temperature for the 10-cm depth at Kona 1 is colder than the 38-cm depth for all months except for June, July, and August. The site at Kona 2 shows a more interesting relationship between the two soil depths. At the Kona 2 site, the 10-cm depth is colder than the 50-cm depth for every month of the year. The same relationship occurred beneath kikuyu grass at the Parker HQ and the Hanaipoe sites **(Figures 4 and 5)**.

Relationship of MAST to Altitude

For the tropics, it has been documented in a least two studies that MAST and altitude have a high R^2. A ten-point transect study in the Caribbean National Forest conducted by the U.S. Forest Service during 1985 and 1986 showed an R^2 of 0.93 between MAST and altitude [Huffaker, L., 1999. Soil Survey of the Caribbean National & the Luquillo Experimental Forests. Submitted for publication. USDA-FS, Atlanta, GA]. Embreachts and Tavernier (1986) reported an R^2 of 0.86 between MAST and altitude for a study in Cameroon, Africa from 15 scattered sites within 10ºN of the Equator. Regression analysis of MAST and altitude for the Hawaiian sites in kikuyu grass is shown in **Figure 6**. The R^2 value of 0.86 verifies that, in Hawaii, there is no precise mathematical model to accurately determine the MAST solely on the basis of altitude. This straight-line regression does accurately point out that the Kona sites are warmer than hypothesized. Many scientists would have conjectured prior to this study that the MAST of the Kona sites would have been 2ºC lower than measured.

Relationship of MAST to MAAT

Smith et al., (1964) cited than in humid oceanic climates when soils receive large amounts of annual rainfall, the MAST at 50-cm is reported to be cooler than the MAAT generally because of the lack of solar radiation or the effect of evaporation. This phenomenon occurred at the Parker HQ site in Waimea but for different reasons than stated by Smith et al. The MAST for the 10-cm depth under kikuyu grass (Pennisetum clandestinum) at the Waimea was cooler than the MAAT (17.4ºC versus 17.7ºC). We conjecture that the kikuyu grass with its thick fibrous root system eliminates any possibility to solar radiation impacting the 10-cm depth. This part of the Parker Ranch is also irrigated during the droughty summer months, slightly lowering the soil temperature at 10-cm.

Isotivity Values

From 1975 to 1998, soil temperature regimes were designated as 'iso' with less than 5ºC (9ºF) difference between average summer and winter soil temperatures at 50-cm depth (Soil Survey Staff, 1975). During the 1980s, research from a climate monitoring network on Haleakala, a mountain on the island of Maui, had shown that 3 out of 19 stations differed more than 5° C at 50-cm which placed these sites as Hyperthermic (Nullet et al., 1990). As a result of this study, the 'iso' definition in Soil Taxonomy was amended to allow isotivity values to range to 6ºC (Soil Survey Staff, 1998). For the 1998-1999 temperature study on Hawaii, the sites under kikuyu grass exhibited low isotivity values for both the 10- and 50-cm soil depths. They averaged 3.2ºC in isotivity value for their 10-cm depths and 2.1ºC in isotivity value for the deeper depths at 38- and 50-cm. These data suggest that soils in the tropics beneath a thick carpet of grass have lower isotivity values than woodland soils.

SUMMARY & DISCUSSION

In many parts of the continental US, the MAST at the 10- and 50-cm soil depth are about the same. In a few rare cases, the difference is as much as 0.5ºC (Mount, H.R. 1999. National air and soil temperature tables. NSSC HomePage, http://www.statlab.iastate.edu:80/soils/nssc/). At four sites in Hawaii, the soil temperature under kikuyu grass consistently shows that the 50-cm depth is 1.2ºC warmer than the 10-cm depth. We offer two possible reasons why this unusual difference occurs. The kikuyu grass is deep rooted and probably keeps the lower soil depths under negative water tension while the near surface is replenished with precipitation throughout most of the year. Since more units of heat are needed to warm wet soil than dry, this difference is manifested throughout the year. Big Island, being the youngest of the Hawaiian island chain, still has active volcanic activity. It is possible that the heat of geologic activity is upwelling toward the soil surface. Consequently, the deeper depths are always warmer on a mean annual basis than the shallow depths under conditions where kikuyu grass thrive. This exothermic activity is suspected at each of the sites in Hawaii. A simple test to prove this hypothesis would be to install temperature sensors at equal 25-cm intervals to a depth of two meters. We encourage this attempt to solve the question of why the soil temperature under kikuyu grass in Hawaii is increasing with depth.

Presented at the NZSSS/ASSSI Soil 2000 Conference in Canterbury, New Zealand, December 2000

REFERENCES

Embrechts, J. and R. Tavernier. 1986. Soil temperature regimes in Cameroon as defined in soil taxonomy. Geoderma, 37:149-155.
Juvik, James O., D.C. Singleton, and G.G. Clarke. 1978. Climate and water balance on the island of Hawaii, IN: Mauna Loa Observatory – A 20th Anniversary Report. Pages 129-138. John Miller, Ed., US Dept Commerce, Air Resources Lab., Silver Spring, MD.
Juvik, J.O., S.P. Juvik, and L.S. Hamilton. 1992. Altitudinal resource zonation versus vertical control: land use conflicts on two Hawaiian mountains. IN: Mountain Research and Development, Vol. 12, No. 3. Univ. Cal. Press.
Juvik, James O. and D. Nullet. 1994. A climate transect through montaine rain forest in Hawaii. Journal of Applied Meteorology. Vol. 33. No. 11. Pages 1304-1312. Amer. Meteor. Society.
Juvik, Sonia P., and P.O. Juvik. 1998. Atlas of Hawaii, third edition. University of Hawaii at Hilo. U of HI Press, Honolulu, HI. Pages 49 to 59. ISBN 0-82248-1745-1.
Meteorological Staff. 1983. Temperatures of Hawaii. State of Hawaii, Dept of Land and Nat. Resources. Div of Water and Land Develop. Honolulu, HI.
Nullet, D., H. Ikawa, and P. Kilham, 1990. Local differences in soil temperature and soil moisture regimes on a mountain slope, Hawaii. Geoderma, 47:171-184
Smith, G.D., F. Newhall, L.H. Robinson, and D. Swanson. 1964. Soil temperature regimes - their characteristics and predictability. Tech. Publ. No. 144, SCS, U.S. Gov. Print. Office, Washington, D.C.
Soil Survey Staff. 1975. Soil taxonomy. USDA-SCS Agric. Handb. 436., U.S. Gov. Print. Office, Washington D.C.

Poster generated by Janet Bauer, Office Automation Assistant, National Soil Survey Center, Lincoln, NE

Figure 1. Location of the Temperature Sites in the Study Area.

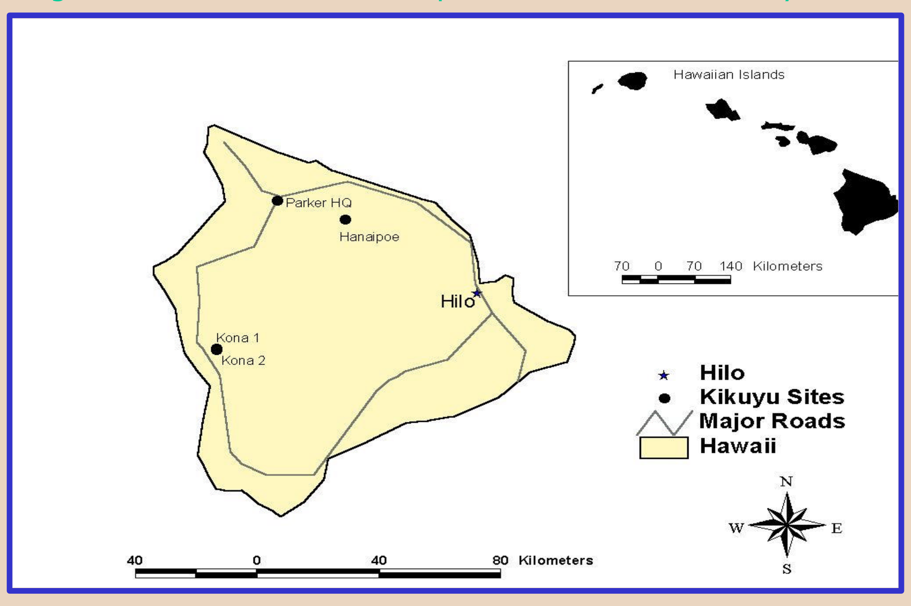

Figure 2. Soil Profile for the Volcanic Soil at the Hanoipoe Site.

Figure 3. Typical Area of Kikuyu Grass Near the Parker HQ Site.

Figure 4. Monthly Air & Soil Temperature at the Parker HQ Site.

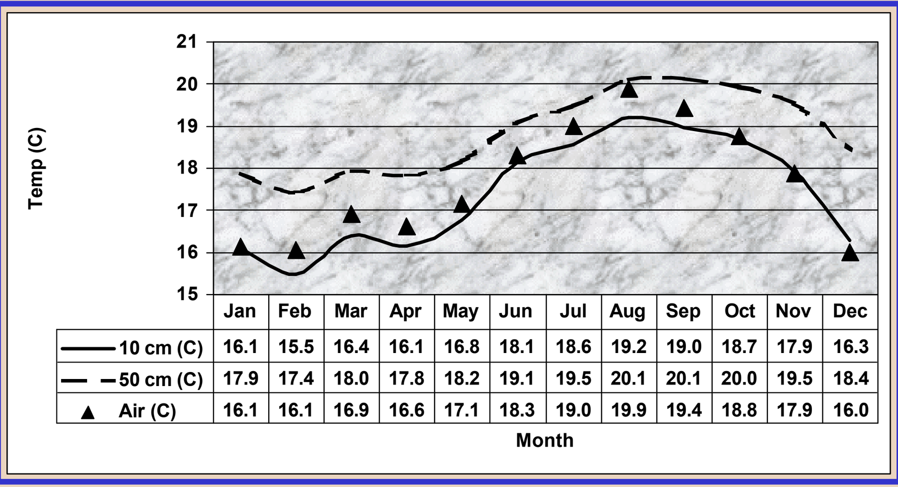

Figure 5. Monthly Air & Soil Temperature at the Hanaipoe Site.

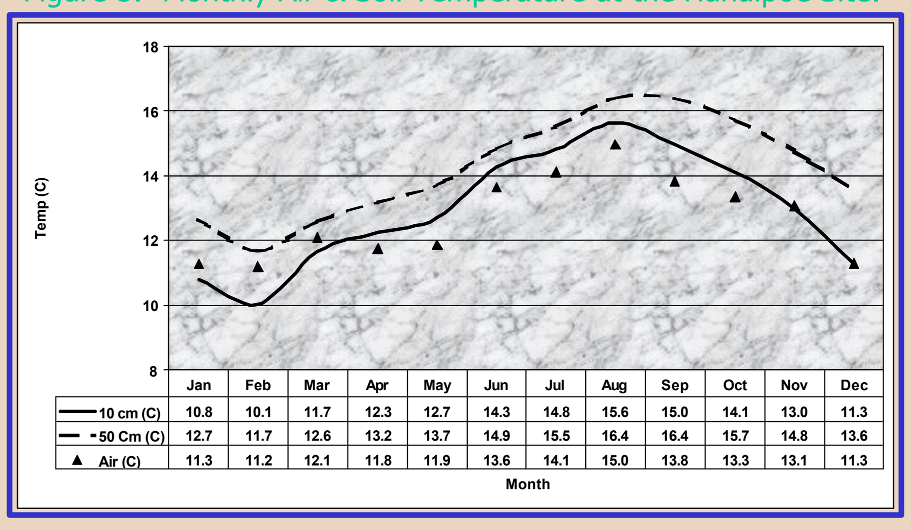

Figure 6. A Straight-line Regression Formula for the Sites in Kikuyu Grass.

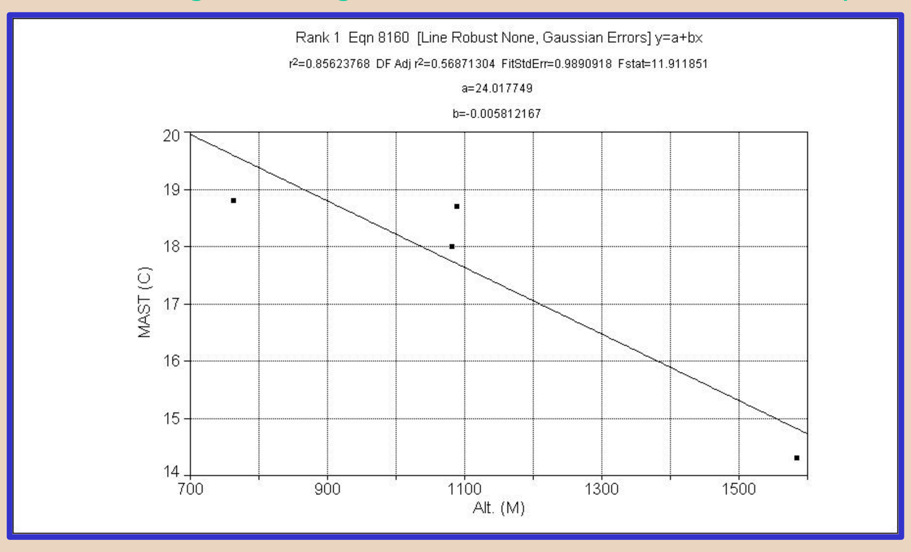

Table 1. Soil and Site Information for the Temperature Sites in Kikuyu Grass.

Site (Name)	Latitude (N)	Longitude (W)	Elevation (m)	Slope (%)	Aspect (º)	Mean Precipitation (mm)
Kona 1	19-30-06.6	155-51-23.4	1089	5	40	1400
Kona 2	19-29-40.8	155-51-24.6	1082	5	40	1400
Parker HQ	20-00-36.6	155-40-35.4	764	2	270	585
Hanaipoe	19-56-41.4	155-28-30.0	1585	13	0	585

Table 2. Soil Temperature Averages Measured in °C for the 10-, 38- and 50-cm Depths at Four Sites in Hawaii.

Analysis (Period)	Kona 1 10-cm	Kona 1 38-cm	Kona 2 10-cm	Kona 2 50-cm	Parker HQ 10-cm	Parker HQ 50-cm	Hanaipoe 10-cm	Hanaipoe 50-cm
Jan	16.8	17.6	16.3	17.0	16.1	17.9	10.8	12.7
Feb	16.0	16.8	15.7	16.2	15.5	17.4	10.1	11.7
Mar	16.5	16.8	16.1	16.5	16.4	18.0	11.7	12.6
Apr	17.4	17.5	16.5	17.0	16.1	17.8	12.3	13.2
May	17.8	17.8	16.8	17.3	16.8	18.2	12.7	13.7
Jun	19.1	18.8	17.8	18.2	18.1	19.1	14.3	14.9
Jul	19.9	19.6	18.8	19.0	18.6	19.5	14.8	15.5
Aug	20.7	20.3	19.2	19.5	19.2	20.1	15.6	16.4
Sep	20.0	20.4	19.1	19.5	19.0	20.1	15.0	16.4
Oct	19.9	20.3	19.3	19.5	18.7	20.0	14.1	15.7
Nov	19.0	19.7	18.2	19.0	17.9	19.5	13.0	14.8
Dec	17.2	18.4	16.5	17.7	16.3	18.4	11.3	13.6
MAST	17.0	18.7	17.5	18.0	17.4	18.8	13.0	14.3
Isotivity	3.3	2.0	2.5	1.9	2.7	1.7	4.2	3.0